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A New, High-Frequency, Broadband Seismic Source

J.M. English, S.T. Inkpen, and J.Y. Guigne, C-Core

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ABSTRACT

A new seismic source has been developed which emits a reproducible, high frequency, broadband acoustic signal. This device, suitable for marine sub-bottom profiling is a unique variation of the multi-electrode sparker source. Calibration experiments performed in "free field" conditions have shown that the output is tunable by varying the power supplied to the source. Typical output has a 4.2 kHz bandwidth and a 3.0 kHz centre frequency, measured 3 dB down, at an operating power of 480 Joules.

INTRODUCTION

Resolution of two seismic reflectors depends on the length of the acoustic pulse. Simply put, the shorter the pulse, the finer the temporal resolution. Taken to the extreme, the ideal pulse would be a spike with all the energy concentrated at a single point in time. Since bandwidth increases with decreasing pulse length, the desired pulse is broad band, containing high frequencies to permit resolution of thinly spaced reflectors, as well as low frequencies which achieve greater sub-surface penetration.[1]

For a given pulse length, the desired shape is 'front end loaded'; having its energy maximally concentrated at the onset.[2] Such a pulse is known as minimum phase. Digital statistical deconvolution processes assume that the source wavelet is minimum phase. The quality of the output from these deconvolution processes degrades as the pulse departs from minimum phase.

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References and figures at end of paper

An acoustic source which delivered the same acoustic signature for an indefinite period of time would reduce the possibility of interpreting a deviation in source signature as a lithologic change in the sub-surface. Finally, an ability to control and alter the length and shape of the emitted pulse would permit a tuning of the source to a particular seabed.

In summary, good quality seismic data depend, among other things, on the length, shape and consistency of the downgoing acoustic pulse, as well as on an ability to alter the pulse in a controlled manner. We have developed an acoustic source based on the common sparker source routinely used in sub-bottom profiling. The conventional multi-electrode sparker has many advantages including its ease of operation, versatility and low cost; however, it does suffer from a degradation in pulse shape through the course of a survey due to the deterioration of electrodes.[3] Our efforts have concentrated on engineering a multi-electrode sparker that emits a minimum phase, reproducible signal with a higher frequency and a broader bandwidth than the conventional sparker. This device was developed specifically for the unique requirements of a stationary high resolution geophysical site surveying tool. [4][5] However, calibration of the source in a towed mode is planned for the next phase of our research. This paper describes the source and shows examples of field data.

SPARKER THEORY

The term sparker is misleading, it tends to imply that the mechanism is the same as that of a spark plug. However, a spark plug is a device which includes a pair of electrodes with an insulator in the inter-electrode space. A disruptive discharge of electricity occurs when the electric field between the electrodes exceeds the dielectric strength of the insulator. In the case of the marine sparker source stored electrical energy is also discharged across two or more electrodes; however, in this case there is a conductor, seawater, in the inter-electrode space. Current then flows between the electrodes and electrical energy is dissipated in the seawater. Rapid heating of the seawater caused by the concentration of the electrical energy at the electrode tips results in the formation of a bubble of steam plus ionized particles. The bubble expands rapidly during the discharge, generating an acoustic pulse. At the end of the discharge the bubble cools and collapses. The collapse of the bubble terminates in a sharp water slap, producing a secondary pulse. The secondary pulse has been measured to be an order of magnitude greater in amplitude than the initial pulse, but shorter in duration. Since most of the steam condenses to water during the bubble contraction cycle, little gas remains so there is only one bubble pulse of any consequence.[6]

As the electrical energy that is delivered to the electrodes is increased, the amplitude and duration of the ensuing pulse increases, with a corresponding decrease in dominant frequency and bandwidth. Thus the inevitable trade-off exists between the amplitude and the frequency content of the pulse produced at the sparker electrode. The principle of a multi-electrode sparker is that by dividing the total electrical energy over several electrodes, the resultant superimposed pulse can have a high frequency content while maintaining a relatively high amplitude. Cassand and Lavergne first demonstrated through experimentation that increasing the number of electrodes could shorten the acoustic pulse.[7]

Other factors that effect the shape and frequency content of the emitted pulse are the surface area of the electrode that is exposed to the seawater, the salinity of the water, and the operating depth. Experimentation has shown that as the electrode surface area is increased the amplitude of the pulse decreases to a point where it can not be detected using conventional hydrophones. The salinity of the seawater surrounding the electrodes has a direct effect on the conductance between the high voltage live and the ground electrodes. If the conductance is too low, such as in a fresh water environment, the electrical

discharge will not take place and no acoustic pulse will form. Increasing depth in the ocean normally means a decrease in temperature; an increase in salinity and density; and an increase in hydrostatic pressure. The increase in pressure most affects the nature of the acoustic pulse; this decreases its amplitude and duration and thereby broadening its bandwidth.[8][9][10]

SOURCE DESIGN

Our experimentation into multi-electrode sparker designs began in early 1987. From the start we outlined several design guidelines: all electrodes would be physically identical within a specified tolerance and would be made of a wear resistant material to avoid pulse degradation; the electrodes would be as small as possible to improve the transducers' efficiency; and the electrodes would be positioned so as to focus a symmetrical pulse downward.

Figure 1 is a cross-sectional sketch of the present device, not drawn to scale. It is constructed of a cylindrical high density polyethylene container ① measuring six inches in height and eighteen inches in diameter. Within this housing there is a one half inch thick ultra high molecular weight polyethylene disk ② which is secured by polyethylene welding. Attached to the underside of this disk is a one eighth inch thick stainless steel plate ③ which we connect to the high voltage live of the seismic energy power supply. One hundred and twenty one stainless steel electrodes ④, all machined to .002 in. tolerance, are threaded into nylon inserts ⑤ which in turn are threaded into the polyethylene and stainless steel disks. The stainless steel electrodes are all connected to the high voltage ground of the seismic energy power supply. The nylon inserts electrically insulate all but the tips of the electrodes from the stainless steel plate. All electrodes are electrically connected within the housing and then this housing is entirely filled with petroleum wax. This wax serves two purposes; it seals the housing to eliminate corrosion of the electrical connections; and, it minimizes the acoustic reflections from inside the housing by displacing the air that would otherwise be trapped there. Finally, the top cover ⑥, an ultra high molecular weight polyethylene disk, is fastened in place.

Stainless steel was chosen as the optimum electrode material following a study of electrode wear observed for several different metals. Figure 2 is a scale drawing of the underside of the source, showing the symmetrical arrangement of the electrodes. Figure 3 is a photograph of an assembled sparker.

This design represents a radical departure from conventional sparker designs, both in its physical embodiment as well as the precision to which it is built. Also unique is the polarity of electrical connections from the source to the seismic energy power supply. Usually the larger electrode is connected to the high voltage ground and the smaller electrodes, the discharge electrodes, are connected to the high voltage live.[10] In support of the observations of Caulfield we found that the polarity of the discharge electrodes affected the amplitude of the acoustic pulse. However, contrary to his findings, our experimentation showed that the most consistent pulse was delivered when the discharge electrodes were connected to the high voltage ground and the large stainless steel plate was connected to the high voltage live. Otherwise, a very erratic pulse was produced.

These innovations have contributed to the invention of a source which emits a consistent high frequency pulse.

CALIBRATION

Calibration of this new source took place in a 20 meter deep salt water bay. Figure 4 shows the experimental set-up. The recording equipment consisted of: a hydrophone with a frequency range of .1 Hertz - 180 kilohertz; a charge preamplifier with built in anti-aliasing filters; an analogue to digital converter with 12 bit accuracy and sample rates up to 2 microseconds; and a 286 portable computer. For our calibrations a 10 microsecond sample rate and a 30 kHz anti-alias filter were employed. All data was recorded digitally and subsequently entered into a geophysical workstation for processing and display.

Figures 5 through 7 demonstrate the reproducibility of the acoustic signature at three operating power levels. The power spectra were calculated from the first trace shown in each of the figures. When operated at 480 Joules the acoustic pulse had a bandwidth of 4200 Hz and a centre frequency of 3000 Hz, measured 3 dB down. When operated at 750 Joules the bandwidth was 3800 Hz with a centre frequency of 2300 Hz, and when operated at 1080 Joules the bandwidth was 3500 Hz with a centre frequency of 2150 Hz. Thus, as previously explained, the characteristics of the acoustic pulse can be controlled by varying the power to the source. Also note the shape of the acoustic pulses and the corresponding phase diagrams. The pulses are very "front end loaded", exhibiting minimum phase characteristics.

CONCLUSIONS

Improvements to the method of developing acoustic pulses using a spark discharge have led to the invention of a source which emits a reproducible, high frequency, broadband pulse, suitable for marine sub-bottom profiling. The acoustic pulse has been shown to be tunable by varying the operating power level. It has also been demonstrated that the source can be operated for extended periods of time with little change in its signature.

ACKNOWLEDGEMENTS

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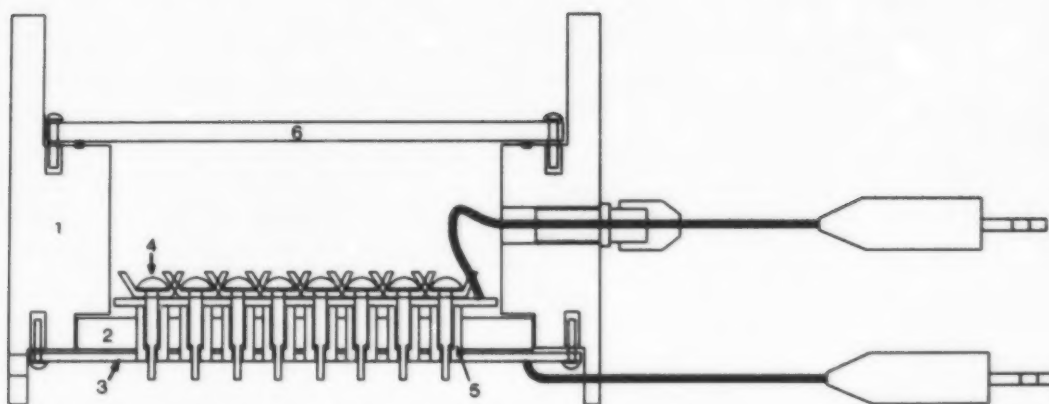


Figure 1: Sparker Cross-Sectional View

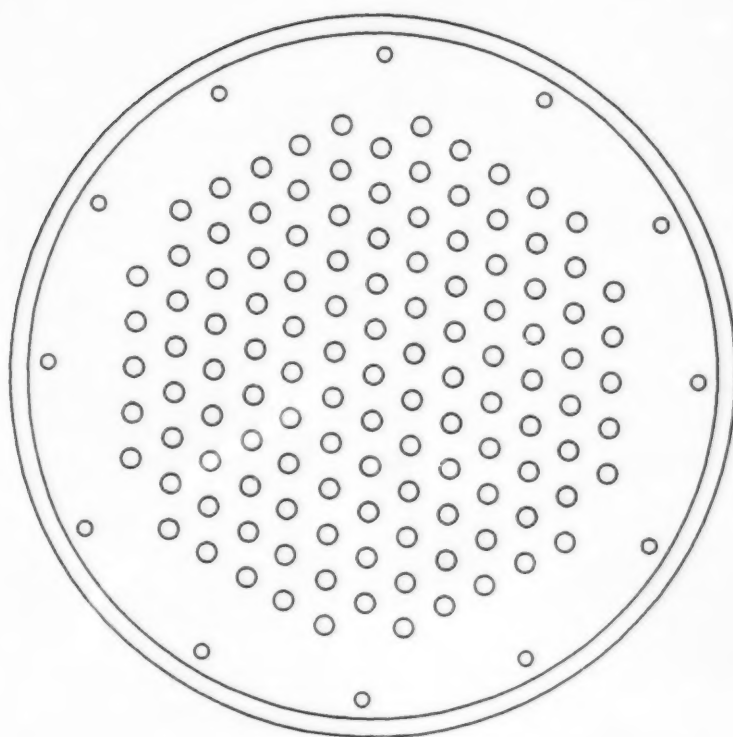


Figure 2: Sparker Bottom View

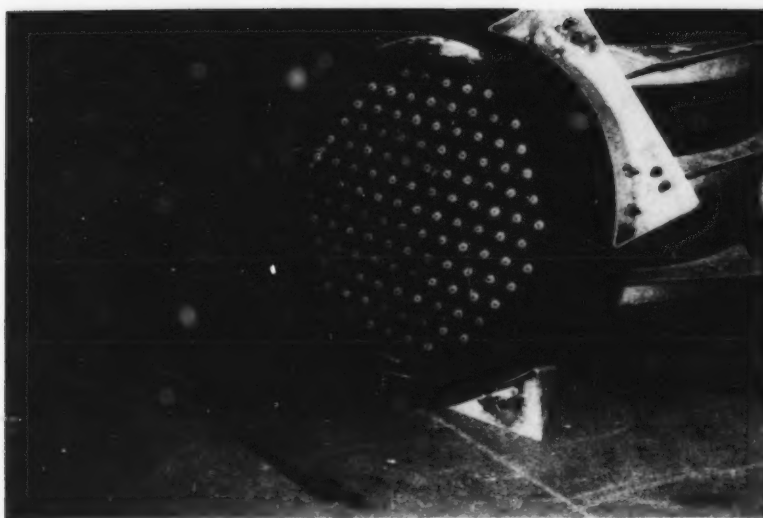


Figure 3: Photograph of Sparker

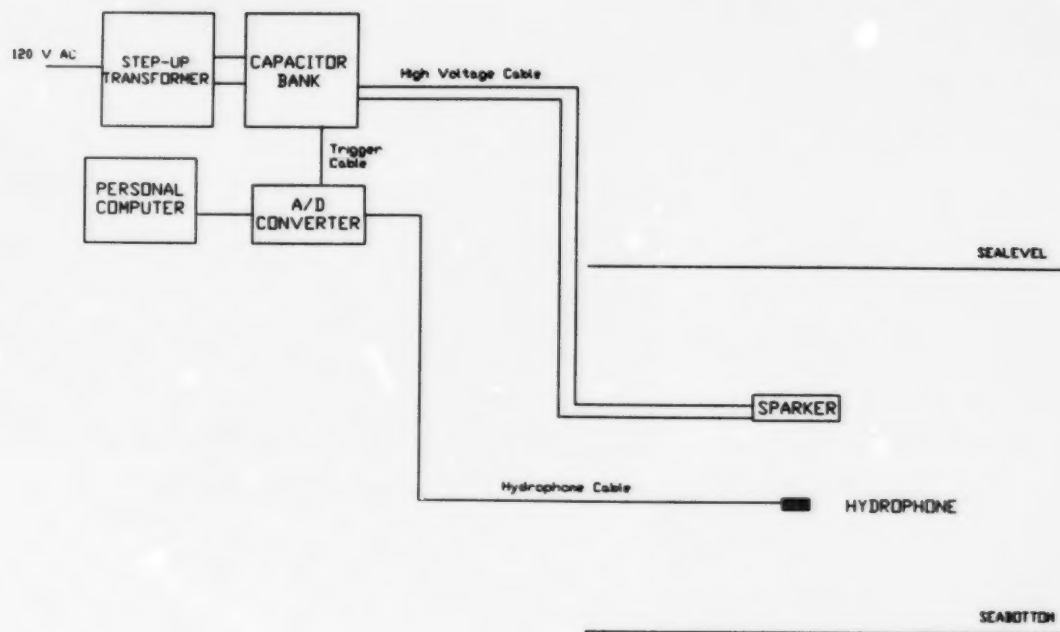


Figure 4: Calibration Set-Up

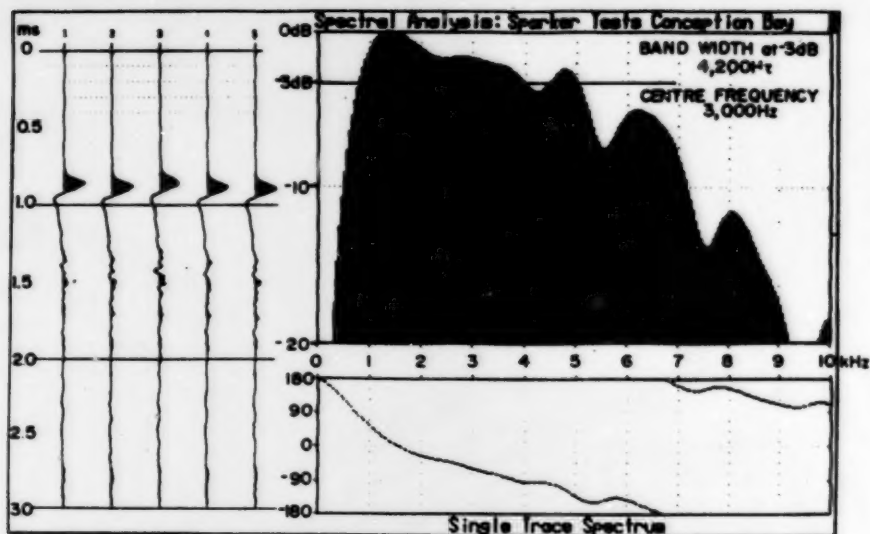


Figure 5: Traces and Power Spectrum, Operating Power 480 Joules

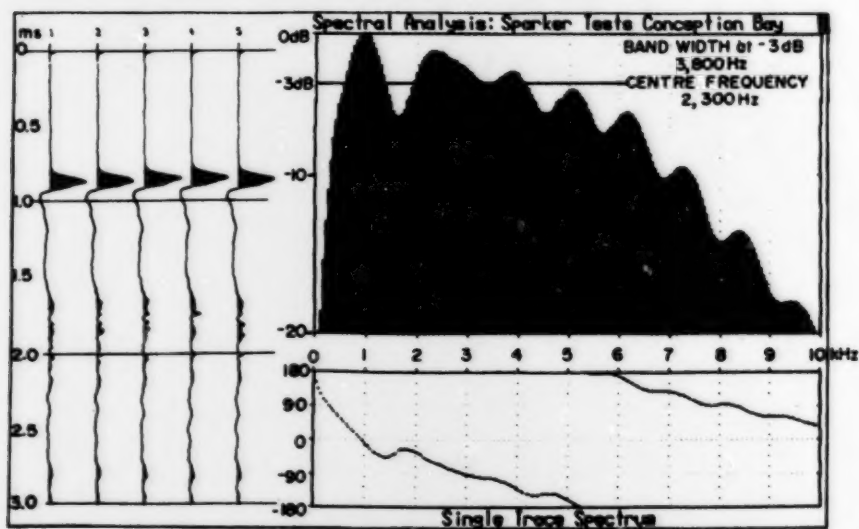


Figure 6: Traces and Power Spectrum, Operating Power 750 Joules

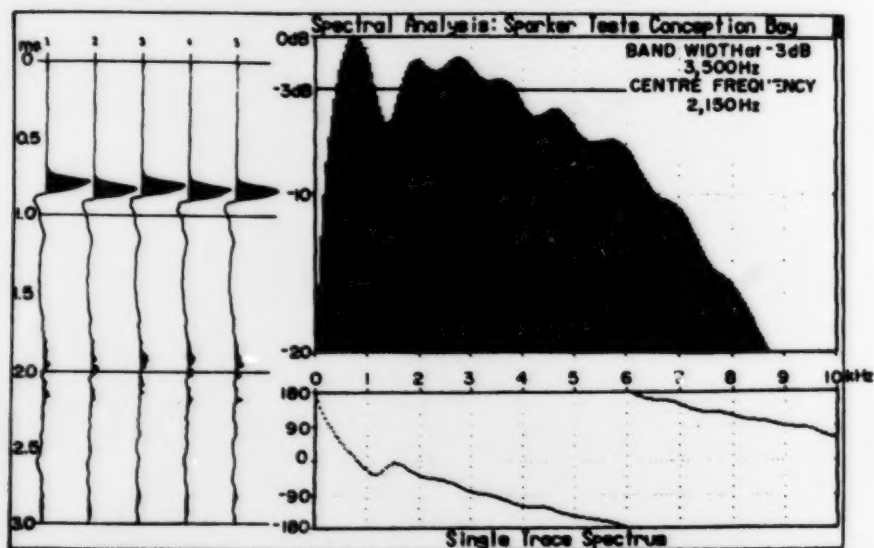


Figure 7: Traces and Power Spectrum, Operating Power 1080 Joules